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High-performance 850 nm vertical-cavity surface-emitting laser in Gigabit Ethernet network

Mohd Sharizal Alias[a], Sahbuddin Shaari[b], P.K. Choudhury[c,*]

[a]*Optoelectronic Device Cluster, Microelectronic & Nanotechnology Program, Telekom Malaysia Research & Development, UPM-MTDC, Serdang 43400, Selangor, Malaysia*
[b]*Institute of Microengineering & Nanoelectronics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*
[c]*Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Selangor, Malaysia*

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Abstract

High-performance oxide vertical-cavity surface-emitting (VCSEL) laser is fabricated, and its usefulness is demonstrated as a suitable transmitting light source at 850 nm operating wavelength for Gigabit Ethernet application. Utilization of barrier reduction layers reveals low-threshold current requirement for operation at high modulation bandwidth. The electrical and optical characteristics, measured from the fabricated VCSEL, are simulated for Gigabit Ethernet transmission. Data rates of 1.25 Gbps with a bit error rate of 10^{-11} are achieved by the use of a specific multimode network simulator.

Keywords: VCSELs; Gigabit Ethernet network; Quantum well devices; Optoelectronic devices

1. Introduction

Nowadays sustained attention towards the communication bandwidth (BW) fuelled the amazing growth rate of commercial optical-communication systems. This has partially imposed a major boost toward the enhancement of data communication prerequisite for high-speed internet networks [1]. The essential requirements are owing to high BW data contents for audio and video applications. The definition of fast-Ethernet technology (100 Mbps), as was in use before, is no longer adequate to cater such high-bandwidth-consuming applications. As such, the Gigabit Ethernet technology (1000 Mbps) currently remains the preferred option for data communication in local area networks (LANs).

In the context of Gigabit Ethernet technology, the efficacy of the use of VCSELs as the light source lies in its capability to modulate at high speed in the optical fiber communication networks. Further, apart from the high-speed current modulation for Gb/s data generation, VCSELs offer additional advantages of low operating threshold current requirement, stable temperature dependence, high fiber coupling efficiency and low fabrication cost. Indeed, the wavelength-division-multiplexing systems and vertical-cavity surface-emitting lasers (VCSELs) facilitate the integration of electronic and photonic components, thereby promising to render optical networks more affordable.

Although much of the current VCSEL research concentrates at long-wavelength (1330–1550 nm) region

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[*] Corresponding author. Fax: +60 3 83183029.
E-mail address: pankaj@mmu.edu.my (P.K. Choudhury).

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of the electromagnetic spectrum, significant interest still remains in the development of 850 nm VCSELs owing to their successful commercialized applications in low-cost optical links and LANs. The relevant R&D community primarily focused the interest in improving the device performance by implementing various techniques such as oxide confinement [2], surface-relief etching [3], extended optical cavity [4], increased fundamental mode gain [5], hybrid implant/oxide structures [6], composite resonators [7] and photonic crystal structures [8]. The designs with such options have been in practice in order to improve typical problems related to VCSELs, viz. multiple transverse mode profiles and self-heating phenomenon.

The present communication reports the characteristics of 850 nm oxide-confined VCSEL device with the implementation of barrier reduction layers [9,10]. The purpose of introducing barrier reduction layers in the VCSEL structure is essentially to improve electrical conductivity of the device, thus lowering the threshold current requirement for operation and reducing the effect due to self-thermal heating. In an earlier communication, Alias et al. [11] reported the fabrication procedure of the oxide-confined 850 nm VCSEL with various oxide aperture sizes followed by the experimental characterization. Their investigations of the electrical and optical characteristics (of the fabricated VCSEL samples) reveal that the devices with oxide aperture size less than 10 μm require low-threshold currents (<1 mA). In this paper too, we report typical electrical–optical characteristics for the fabricated 850 nm oxide-confined VCSELs with barrier reduction layers. The experimental data are then put into simulation for Gigabit Ethernet in LAN with the fabricated VCSEL as the transmitting light source. The simulation is performed by using specific optical network software (RSoft) for multimode operation. In our work the dispersive effect in multimode operation is also taken into consideration, and therefore, we understand that the results will essentially reveal the steps toward the first demonstration of accurate Gigabit Ethernet simulation of VCSEL in multimode environment.

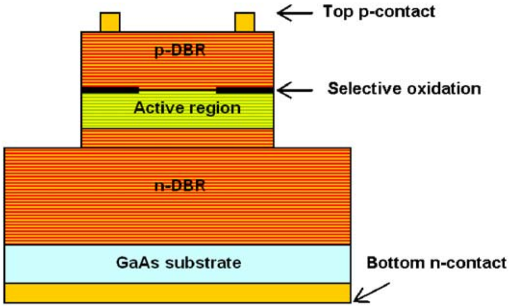

Fig. 1. Schematic of the 850 nm VCSEL device.

2. Device structure and experimental method

Fig. 1 shows the schematic of 850 nm VCSEL with barrier reduction layers. The VCSEL structure consists of a bottom 34.5 periods of n-type distributed Bragg reflector (DBR) mirrors, an active region of three GaAs quantum wells and a top 24.5 periods of p-type DBR mirrors, all grown by metal-organic chemical vapor deposition. Both the DBR mirrors are composed of alternating high and low refractive index (RI) quarter wavelength layers of $Al_{0.9}Ga_{0.1}As/Al_{0.15}Ga_{0.85}As$ with the barrier reduction layers of $Al_{0.47}Ga_{0.53}As$ embedded in between. Underneath the top p-DBR mirror, the $Al_{0.98}Ga_{0.02}As$ layer was introduced for the purpose of selective oxidation.

The VCSEL device fabrication began with the definition of a top ring contact pattern using standard optical lithography. Ti/Au (15 nm/150 nm) layer was then evaporated, and lifted off; this forms the ohmic contacts to the p-type top DBR. The backside (n-type) ohmic contact was formed by the evaporation of AuGe/Ni/Au (40 nm/20 nm/150 nm). These evaporations were performed using both thermal and electron beam evaporation methods. In order to isolate the various VCSEL devices and expose the high RI Al layer for oxidation, mesa structures were defined. To do this, SiO_2 dielectric layer was deposited first by the process of plasma-enhanced chemical vapor deposition, and subsequently patterned by the use of standard optical lithography and CF_4 reactive ion etching (RIE). This patterned dielectric layer was then used as the mask for the mesas which were etched by inductively coupled plasma RIE. The high RI Al layer was then selectively oxidized by the process of wet oxidation in order to define the oxide aperture. The SiO_2 mesa mask was removed by the process of CF_4 RIE.

Fig. 2 shows the measurement setup used to characterize the electrical and optical characteristics of the fabricated VCSEL. Current is supplied by the DC current source (Keithley 236) or a semiconductor

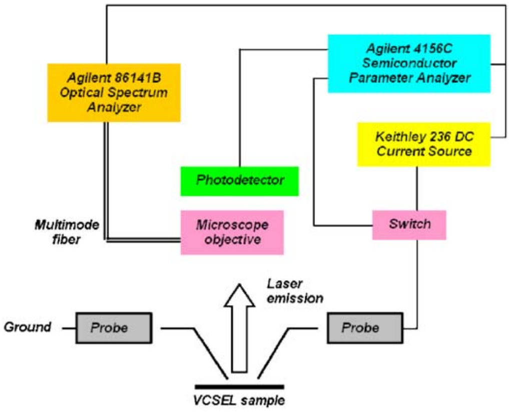

Fig. 2. Schematic of the VCSEL measurement setup.